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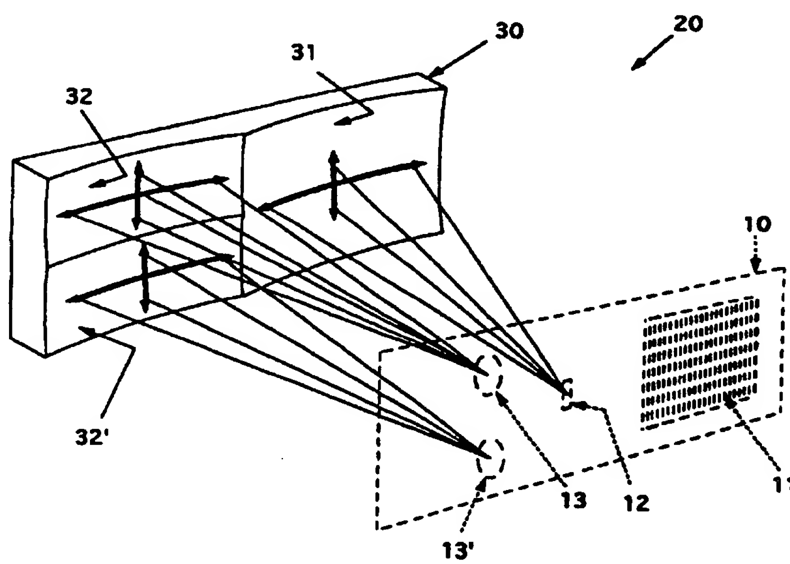

(57) Abstract

A spectrometer (20) is formed from two supports (10, 30). A first of the supports (10) has a diffraction grating (11) for dispersing light, source locating means (12) for locating a source of said light, and detector locating means (13) for locating a detector of said dispersed light. The other support is a mirror support (30) having a body and at least two reflective surfaces (31, 32) integrally formed with the body of the support (30). In preferred embodiments, one of the reflective surfaces may be divided into segments (32, 32'; 33). The spectrometer (20) can be cheaply mass-produced. In aspects of the invention, the distances between the source, detector and dispersive means are accurately fixed during manufacture in a simple and inexpensive manner.

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SPECTROMETER

The present invention relates generally to spectrometers.

In WO-A-95/10037, there is disclosed a spectrometer. The spectrometer disclosed is particularly useful for detecting the presence of a target gas, such as carbon monoxide, in a mixture of gases, for example in the atmosphere. Light from a source is dispersed by a diffraction grating. Spaced apart opto-electric transducers detect different dispersed wavelengths. The amount of light detected at each detector varies according to the amount of light in a particular wavelength absorbed during its passage through the target gas to be detected.

The narrow band of wavelengths which are detected by the spaced apart detectors is a sensitive function of the optical geometry of the spectrometer. In particular, the source, grating and detector must be positioned relative to one another with a very high degree of accuracy. This makes it very difficult to mass-produce the spectrometer, which is desirable in order to reduce the overall cost of the spectrometer.

The optical layout of a typical conventional spectrometer is shown in Figure 1. A source 1 of light is typically a slit or aperture illuminated from behind by a tungsten filament lamp. Light from the source 1 passes to a first parabolic mirror 2 which produces and directs a plane wave towards a diffraction grating 3. The diffracted plane wave is collected by a second parabolic mirror 4 which reflects and focuses an image of the source onto a detector 5. Since the angle of diffraction of the light from the diffraction grating 3 varies with wavelength, the spectrometer effectively produces an infinite number of

images, each at a different wavelength, spread across the plane of the detector 5. As will be seen from Figure 1, the source 1 and detector 5 are on opposite sides of the diffraction grating 3. This causes the conventional spectrometer to be rather large.

According to a first aspect of the present invention, there is provided a unitary support for a spectrometer, the support comprising: dispersive means for dispersing light incident on the dispersive means; source locating means for locating a source of said light with respect to the dispersive means; and, detector locating means for locating a detector of said dispersed light with respect to the dispersive means.

Preferably, the support is moulded.

The support is preferably made of plastics. The support may be made by moulding of plastics. Injection moulding, compression moulding, or vacuum-assisted injection moulding, or a combination, may be used, for example.

The source locating means, the detector locating means, and the dispersive means are preferably substantially coplanar. The source locating means and detector locating means are preferably positioned on the same side of the dispersive means.

According to a second aspect of the present invention, there is provided a support for a spectrometer, the support comprising: dispersive means for dispersing light incident on the dispersive means; source locating means for locating a source of said light with respect to the dispersive means; and, detector locating means for locating a detector of said dispersed light with respect to the dispersive

means; the source locating means, the detector locating means and the dispersive means being substantially coplanar, the source locating means and detector locating means being positioned on the same side of the dispersive means.

In either aspect of the invention, the source locating means may be an aperture through the support. The "actual" light source is positioned in use behind the aperture. The aperture may be a slit. The actual light source may be a tungsten filament lamp for example.

The dispersive means may be a diffraction grating. The diffraction grating may be integrally moulded with the support. The diffraction grating may be formed by moulding the grating structure and metallising the grating structure.

The detector locating means may be a hole through the support. Such a hole can locate one or more detectors. There may be two through holes for locating two respective detectors.

According to a third aspect of the present invention, there is provided a unitary mirror support for a spectrometer, the support comprising: a body; and, at least two reflective surfaces integrally formed with the body of the support.

The support is preferably made of plastics. The support may be made by injection-moulding of plastics. Compression moulding or vacuum-assisted injection moulding, or a combination, may be used.

The reflective surfaces may be formed by metallising selected portions of the mirror support.

The reflective surfaces are preferably substantially adjacent.

One of the reflective surfaces may be segmented such that the dispersed light incident on said reflective surface is focused into two or more planes of dispersion. The areas of the segmented portions of the mirror may be different from one another.

The present invention also includes a spectrometer including a support according to either of the first two aspects as described above and a mirror support as described above.

The spectrometer may have two or more dual-element detectors, or one or more quad-element detector, or a combination of dual-element and quad-element detectors.

As will be appreciated from the more detailed description below, the various aspects of the present invention allow a spectrometer to be cheaply mass-produced. In aspects of the invention, the distances between the source, detector and dispersive means are accurately fixed during manufacture in a simple and inexpensive manner. The preferred method of forming the various supports is by use of injection moulded plastics, which is relatively straightforward and inexpensive.

In preferred embodiments of the present invention, just two supports are required to support all of the "active" optical parts of the system. The only alignment required is between the mirror support and the support for the source locating means, the detector locating means and the dispersion means. Where plastics moulding is used for the support for the dispersive means, source locating means and detector locating means, it is preferred that no non-

uniformities lie between an injection moulding point and the active surface of the dispersive means, which in turn means that the source locating means and detector locating means should be on the same side of the grating.

The present invention also provides a spectrometer layout which is extremely compact.

In the present specification, reference will often be made to "light". It will be understood that this term encompasses any suitable electromagnetic radiation. For example, infra-red radiation will usually be used where the target gas to be detected is carbon monoxide.

Embodiments of the present invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a diagrammatic representation of the optical layout of a conventional spectrometer;

Figure 2 is a plan view of a support for a source, detector and diffraction grating;

Figure 3 is a cross-sectional view on III-III of Figure 2;

Figures 4a and 4b are diagrammatic representations of the optical layout of a spectrometer using supports of the present invention;

Figures 5a to 5d are representations of the image formed in the plane of the detector;

Figure 6 is a diagrammatic perspective view of the spectrometer showing a first example of a mirror support;

Figure 7 is a diagrammatic perspective view of the spectrometer showing a second example of a mirror support;

Figure 8 shows a graph of variation of output from two detectors with temperature of the light source;

Figure 9 shows a graph of the difference between said outputs;

Figure 10 shows a contour plot of the difference signal;

Figure 11 shows a contour plot of the ratio of the output of two detectors of a first example; and,

Figure 12 shows a contour plot of the ratio of the output of two detectors of a second example.

A support 10 for locating a light source, a light detector and a diffraction grating 11 is shown in Figures 2 and 3. The support 10 is made of injection moulded plastics. The grating structure of the diffraction grating 11 is integrally moulded with the rest of the support 10 by virtue of the moulding tool having the grating structure mechanically reproduced in it. The grating structure on the support 10 is metallised with say gold or aluminium after moulding to provide the reflective surface. The support 10 is generally in the form of a plane rectangular sheet.

A source locating means 12 is constituted by a hole or aperture or slit 12 through the sheet of the support 10. As shown in Figure 3, the source aperture 12 preferably has a frustoconical cross-sectional shape.

A detector locating means 13 is constituted by a relatively large circular hole through the sheet of the support 10. A lip 14 may be provided around the circumference of the detector hole 13 which enables a detector (not shown in Figures 2 and 3) to be pushed into the support 10 and retained by the lip 14.

The distance a between the diffraction grating 11 and the source slit 12, the distance b between the diffraction grating 11 and the detector hole 13, and the distance b-a between the source slit 12 and detector hole 13 are all critical to the accuracy of the spectrometer. These distances a, b, b-a must be fixed very accurately. This is facilitated by the unitary nature of the support 10. It is further facilitated by moulding the support 10 of plastics, most preferably by injection moulding, as the relative positioning of the diffraction grating 11, the source slit 12 and the detector hole 13 can be accurately determined by the mould used. The direction of flow of the plastics during injection should be from right to left in Figure 2 so that the flow of plastics over the diffraction grating 11 is not disturbed by the irregularities formed by the source slit 12 and detector hole 13. This prevention of irregularities in the flow of plastics over the diffraction grating 11 is ensured because the source slit 12 and detector hole 13 are both positioned on the same side of the diffraction grating 11 (i.e. to the left in Figure 2), the diffraction grating 11, the source slit 12 and detector hole 13 all being substantially coplanar. The fixing of the source slit 12 and detector hole 13 on the same side of the diffraction grating 11 also means that the various optical parts fit into a smaller space than in the prior art, thereby providing a more compact spectrometer. It furthermore allows the two mirror surfaces of the spectrometer to be substantially adjacent as will be discussed in more detail below.

Referring to Figure 4a, a spectrometer 20 includes the support 10 and an opposed mirror support 30. The mirror support 30, which will be discussed in more detail below, supports two substantially adjacent mirrors 31,32. The mirrors 31,32 may be parabolic or some other aspheric shape to reduce aberrations. The mirrors 31,32 may be provided by moulding the mirror support 30 to the appropriate shape and metallising selected portions of the surface of the support 30 with say gold or aluminium to provide integral reflective surfaces for the mirrors 31,32.

The spectrometer 20 includes a tungsten filament lamp 21 as an actual light source which is fixed behind the source slit 12 of the support 10. A detector 22 is fixed into the detector hole 13. The detector 22 may be an opto-electric detector, particularly a pyroelectric detector suitable for detecting infra-red radiation. The detector 22 should be a dual-element detector having two adjacent detecting elements as described in more detail in WO-A-95/10037 so that at least two distinct wavelengths can be detected. The spectrometer 20 may be battery or mains powered.

As can be seen from Figure 4a, light emitted from the actual light source 21 is directed from the source slit 12 (which provides a slit source) to the first mirror 31. The mirror 31 reflects the light as a plane wave towards the diffraction grating 11. Light incident on the diffraction grating 11 is dispersed. This dispersal of light is shown in Figure 4b where different wavelengths are diffracted through different angles. The diffracted light is reflected and focused by the second parabolic mirror 32 onto the detector 22. Because the diffraction grating 11, source slit 12 and detector hole 13 are coplanar or substantially coplanar, the central ray of the optic system is normal or close to normal to the surface of the support

10. This has the advantage that the source slit 12 is easier to mould and that the mould tool in which the support 10 is moulded can open more easily. It is important that the tool face pulls away from the structure of the diffraction grating 11 without any shear. Furthermore, the light window of the detector 22, which would usually have an interference filter coating, will be at peak transmittance.

As can be seen from Figure 4b, light of different wavelengths is focused onto different spaced apart positions on the detector 22. This is shown in Figure 5a, which is a representation of the image of the source slit 12 formed on the detector 22. The wavelength λ1 is the absorption wavelength and λ2 is the reference wavelength. Details of how these wavelengths are used to detect the presence of a target gas can be found in WO-A-95/10037. Briefly, the target gas preferentially absorbs light in the absorption wavelength λ1 whilst having substantially no effect on the reference wavelength λ2. Suitable electronics can monitor for falls in the amount of light being detected in the absorption wavelength relative to the reference wavelength, thereby providing a quantitative measure of the amount of target gas in the optical path.

For a filament lamp or other black body source, the amount of light at a particular wavelength is a function of the temperature of the light source 21, generally in accordance with the Planck distribution law. Assuming a range of temperatures of say 1800 to 2400 K for the filament of the light source 21 and considering wavelengths in the region of 4.5 microns, the absolute amount of light can vary by between 2% and 3% over this temperature range. The detector 22 will generally only be looking for changes of about 0.2% in the amount of light in the absorption wavelength. Clearly, therefore, there is a risk that

temperature variations in the filament of the light source 21 could swamp the changes being monitored in the absorption wavelength level. Furthermore, the real signal to be detected is obviously very small compared to any background signals.

This problem can be overcome by monitoring a third wavelength of light $\lambda 3$, as is mentioned in WO-A-95/10037. The third wavelength $\lambda 3$ could be shorter or longer than the first two wavelengths $\lambda 1$, $\lambda 2$ and this is indicated in Figure 5b where $\lambda 3$ is shown as being either to the left or to the right of the first two wavelengths in the image plane.

The optical system can only produce a sharp focus at one wavelength. At other wavelengths, off-axis aberrations cause the slit image to broaden and blur. In order to make the spectrometer 20 as sensitive as possible, it is designed so that the absorption wavelength $\lambda 1$ is sharply focused. This means that the first reference wavelength $\lambda 2$ will be slightly out of focus, but in practice this is not a problem. If, however, the second reference wavelength $\lambda 3$ is further away from the absorption wavelength $\lambda 1$ than the first reference wavelength $\lambda 2$ (i.e. further to the right in Figure 5b), then the image at the second reference wavelength $\lambda 3$ may not be acceptably focused as the defocusing effect can become quite serious at this distance. On the other hand, the absorption spectra of many target gases of interest can make it unfavourable for the second reference wavelength $\lambda 3$ to be on the opposite side of the absorption wavelength $\lambda 1$ to the first reference wavelength $\lambda 2$ because many target gases of interest have double absorption peaks. This may mean that a second absorption peak coincides with the position of the second reference wavelength $\lambda 3$ in the image plane.

In a preferred embodiment of an aspect of the present invention, this is solved by modifying the second mirror 32. In particular, the second mirror 32 is divided longitudinally of the mirror support 30 to form two adjacent second mirrors 32, 32', one above the other in the configuration shown in the drawings. One or both of the secondary second mirrors 32, 32' is tilted about a horizontal axis in Figure 6 so that each of the secondary second mirrors 32, 32' produces its own vertically spaced set of images. The support 10 for the detector has two detector locating holes 13, 13' for supporting and locating respective detectors for the two vertically spaced images. The two vertically spaced images of the absorption wavelength $\lambda 1$ and first reference wavelength $\lambda 2$ are shown in Figure 5c for this simple example.

As a further development of this split mirror 32, 32' configuration, one of the split mirrors, for example the lower secondary second mirror 32', can be slightly rotated about a vertical axis with respect to the other (upper) secondary second mirror 32. The effect of this is shown in Figure 5d where the upper two images are produced by the upper secondary second mirror 32 and the lower two images are produced by the lower secondary second mirror 32'. The arrangement is preferably such that the absorption wavelength $\lambda 1$ is sharply focused by the upper secondary second mirror 32 on the upper image plane in Figure 5d whereas, in the lower image plane in Figure 5d, the first reference wavelength $\lambda 2$ is sharply focused by the lower secondary second mirror 32'. This particular arrangement has the advantage of enabling use of commercially available multi-element detectors. Commercially available multi-element detectors having four detecting elements are mass-produced for use in motion detectors, for example, and the elements are arranged in a square array. Alternatively, two dual-elements can be used for the detectors, the

elements being mounted in the respective detector locating holes 13, 13' shown in Figure 6. Whichever configuration for the detector is used, the four elements of the detector or detectors can gather all of the information required to compensate or otherwise allow for changes in the temperature of the bulb of the light source 21.

A yet further problem can arise with the potential change in temperature of the light source 21, again because of the temperature dependence of the amount of light emitted in any one particular wavelength. The amount of light in each wavelength is different, and will also vary by a differing amount for each wavelength as the temperature of the light source varies. Accordingly, different amounts of light fall on the absorption and reference detector elements as the temperature of the light source changes, even in the absence of absorption by a target gas. This background variation can make it difficult to observe the real absorption signal. This can be overcome by arranging the respective areas of the secondary second mirrors 32, 32' so that the ratio of the light directed to the two sets of detectors in Figure 5d is such that each pair of detectors for the upper and lower images produces the same signal in the absence of absorption by a target gas. A straightforward differencing circuit then produces a null signal at zero absorption. Careful selection of the wavelengths used for the particular target gas leads to this null signal being valid over a useful range of temperatures for the light source.

Indeed, the second mirror 32 can be divided into any convenient number of segments to provide the required two planes of dispersion to produce the two sets of images 13, 13' and in the desired amount according to the areas of the respective sets of mirror segments. For example, as shown in Figure 7, the second mirror 32 can be divided into an

array of 5 x 5 segments 33. This ensures that the whole wavefront is sampled by both upper and lower sets of segments 33, thereby eliminating any problems that might otherwise be caused by non-uniformity of the wavefront.

In a particular example, the spectrometer 20 is used for detecting the presence of carbon monoxide (CO) as a target gas. The diffraction grating 11 has 154 grooves per mm. The second mirror 32 has a focal length of 92.5mm and an off-axis angle of 30°. This gives the dispersion required to separate by 2mm at the focal plane the absorption wavelength $\lambda 1$ of 4.608 microns and the first reference wavelength of 4.495 microns when the angle of incidence at the grating is 12°. This separation of 2mm matches the detector separation of most commercially available dual-element pyroelectric detectors. The first mirror 31 has a focal length of 101mm and an off-axis angle of 12° to collimate the light from the source 21 onto the diffraction grating 11. The focal points of the two mirrors 31, 32 are coplanar with the diffraction grating 11.

For the segmented mirror shown in Figures 6 and 7, the upper secondary mirror 32 may produce an upper pair of images at 4.608 microns and 4.495 microns and the lower secondary mirror 32' may produce a pair of images at 4.495 microns and 4.382 microns respectively. Because of the Planck distribution, there will be a signal P1(T) from the upper detector pair at zero absorption which will be equivalent to between about 6% and 8% over a range of filament temperatures between 1800K to 2400K, as shown in Figure 8. The output from the lower detector at zero absorption is shown as P2(T) in Figure 8. The difference P1(T)-P2(T) between these two signals is shown in Figure 9. It will be appreciated from Figure 9 that, firstly, the difference is small compared to the expected absorption

signals. The difference is also relatively constant over a fairly wide temperature range. By altering the ratio of the areas of the upper and lower second mirrors 32, 32' as described above, it is possible to "tune out" any background signals which might be wavelength dependent, such as absorption in the glass envelope of the filament lamp, wavelength-dependent reflection coefficients, etc.

An advantageous use of the output of the reference pair of detectors corresponding to the lower pair of images in Figure 5d is to control the temperature of the light source 21. In particular, as can be seen in Figure 8, in this particular example the non-absorption signals P1(T) and P2(T) are both very small at about 700K. This enables the reference pair (P2(T)) to be used to set the temperature of the light source. The voltage of the power supply to the light source 21 (which in the preferred embodiment is a tungsten filament lamp) is varied until a minimum signal for P2(T) is obtained. At this temperature and light output, the main signal P1(T) is also very small so that any real absorption by a target gas is easily discriminated. The slight disadvantage of this method is that the absolute power output from the light source 21 at the wavelengths of interest decreases as the filament temperature reduces, but on the other hand the fraction of useful power from the bulb increases more rapidly. Thus the electrical efficiency of the bulb increases, which is important and useful in a battery powered spectrometer 20.

The reference pair (P2(T)) could also be used to set the light source at any required temperature by minimising the difference between P2(T) and a pre-set voltage reference set by a Zener diode or a band gap device for example. The ability to set the temperature of the source at any desired level allows the power and efficiency of the source to be traded against its lifetime, and can also be

used to compensate for wavelength-dependent losses in the optical components.

In the examples described above, the absorption of the target gas is characterised by the difference in signal output between the two pairs of detectors, i.e. P1(T)-P2(T). This has the advantage of being very easy to arrange electronically, but may have two disadvantages, depending on the application of the invention. Firstly, the degree of compensation for changes in T will be a function of the strength of the absorption signal. This may not be a problem if the device is used in practice to monitor only small changes in a gas concentration, but may be a problem if the gas concentration is expected to cover a wide range. In Figure 10, a contour plot of values of P1(T)-P2(T), in Volts, is shown against carbon monoxide concentration in parts per million (ppm) and filament temperature in Kelvin. The absorption wavelength and first reference wavelength are 4.608 and 4.495 microns respectively, and the second and third reference wavelengths are 4.495 and 4.382 microns respectively. Figure 10 indicates the problem of using a simple difference of signals to characterise the absorption due to the target gas.

The second possible problem is that the signal P1(T)-P2(T) is sensitive to the overall light throughput. This throughput can be expected to change during the life of the spectrometer, due to changes in the reflectivity of the optical surfaces, fogging of the filament lamp envelope, etc. Such changes may introduce a calibration drift. With this in mind, in another example of the spectrometer 20, the absorption of the target gas is characterised by using the ratio of the two detector signals, i.e. P1(T)/P2(T).

In a particular example, the diffraction grating 11 has 120 grooves per mm. The upper second mirror 32 has a focal length of 85.47mm and off-axis angle of 26.7°. With the first mirror 31 arranged to give an angle of incidence of 6° at the grating, the upper second mirror 32 produces the absorption wavelength of 4.608 microns and the first reference wavelength of 4.446 microns on the first pair 13 of detector elements. The lower second mirror 32' has a focal length of 87.42mm and off-axis angle of 23.9°. This lower second mirror 32' directs the second reference wavelength of 4.25 microns onto one element of the second pair 13' of detectors. The second element of the second pair 13' of detectors is blanked off. The contour plot in Figure 11 shows values of P1(T)/P2(T). The temperature sensitivity is now much more consistent with a range of gas concentrations. Figure 12 shows a further improvement when the reference wavelength is changed from 4.25 to 3.6 microns, but this wavelength suffers from slight interference from absorption by methane, which makes it less attractive in some applications.

It will be appreciated that there is a huge range of choices for the values of reference wavelengths, and that the details of the electronic signal processing can be varied to suit each potential application.

As a yet further alternative, a spectrometer 20 including the segmented mirror 32 could be used to sense for two or more gases. This can be done by using a segmented mirror like that in Figure 6 or Figure 7, using two planes of dispersion, each looking on and off absorption for their respective gases. Alternatively, the segmented mirror 32 could be effectively segmented into say three portions in order to provide three planes of dispersion thereby to provide three vertically spaced sets of images in the detector plane. This would allow

detection of two gases and still allow the temperature compensation mentioned above to be utilised. Indeed, if it is desired to detect n gases and provide the temperature control mentioned above, there should be n+1 distinct segments of the second mirror 32 providing n+1 planes of dispersion.

Embodiments of the present invention have been described with particular reference to the examples illustrated. However, it will be appreciated that variations and modifications may be made to the examples described within the scope of the present invention.

CLAIMS

1. A unitary support for a spectrometer, the support (10) comprising:

dispersive means (11) for dispersing light incident on the dispersive means;

source locating means (12) for locating a source of said light with respect to the dispersive means; and,

detector locating means (13) for locating a detector of said dispersed light with respect to the dispersive means.

2. A support according to claim 1, wherein the support is moulded.

3. A support according to claim 1 or claim 2, wherein the support is made of plastics.

4. A support according to claim 1, wherein the support is made by moulding of plastics.

5. A support according to any of claims 1 to 4, wherein the source locating means (12), the detector locating means (13), and the dispersive means (11) are substantially coplanar.

6. A support according to claim 5, wherein the source locating means (12) and detector locating means (13) are positioned on the same side of the dispersive means (11).

7. A support for a spectrometer, the support (10) comprising:

dispersive means (11) for dispersing light incident on the dispersive means;

source locating means (12) for locating a source of said light with respect to the dispersive means; and,

detector locating means (13) for locating a detector of said dispersed light with respect to the dispersive means;

the source locating means (12), the detector locating means (13) and the dispersive means (11) being substantially coplanar, the source locating means (12) and detector locating means (13) being positioned on the same side of the dispersive means (11).

8. A support according to any of claims 1 to 7, wherein the source locating means is an aperture (12) through the support (10).

9. A support according to claim 8, wherein the aperture is a slit (12).

10. A support according to any of claims 1 to 9, wherein the dispersive means is a diffraction grating (11).

11. A support according to claim 10, wherein the diffraction grating (11) is integrally moulded with the support (10).

12. A support according to claim 10 or claim 11, wherein the diffraction grating (11) is formed by moulding the grating structure and metallising the grating structure.

13. A support according to any of claims 1 to 12, wherein the detector locating means comprises a hole (13) through the support.

14. A support according to claim 13, comprising one or more detectors (22) located in said detector locating hole (13).

15. A support according to any of claims 1 to 12, wherein the detector locating means comprises two through holes (13,13') for locating two respective detectors.

16. A unitary mirror support for a spectrometer, the support (30) comprising:

a body; and,

at least two reflective surfaces (31,32) integrally formed with the body of the support (30).

17. A support according to claim 16, wherein the support is made of plastics.

18. A support according to claim 16 or claim 17, wherein the reflective surfaces (31,32) are formed by metallising selected portions of the mirror support.

19. A support according to any of claims 16 to 18, wherein the reflective surfaces (31,32) are substantially adjacent.

20. A support according to any of claims 16 to 19, wherein one (32) of the reflective surfaces is segmented (32,32';33) such that dispersed light incident on said reflective surface (32) is focused into two or more planes of dispersion.

21. A support according to claim 20, wherein the areas of the segmented portions (32,32';33) of the mirror (32) are different from one another.

22. A spectrometer (20) comprising a support (10) according to any of claims 1 to 15 and a mirror support (30) according to any of claims 16 to 21.

23. A spectrometer according to claim 22, comprising two or more dual-element detectors.

24. A spectrometer according to claim 22, comprising at least one quad-element detector.

25. A spectrometer according to claim 22, comprising a combination of dual-element and quad-element detectors.

PRIOR ART

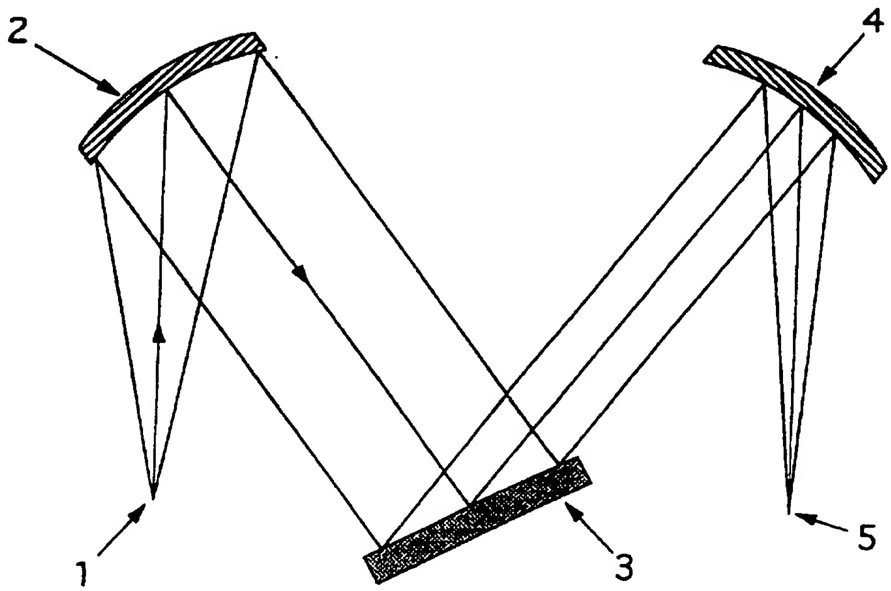


Figure 1

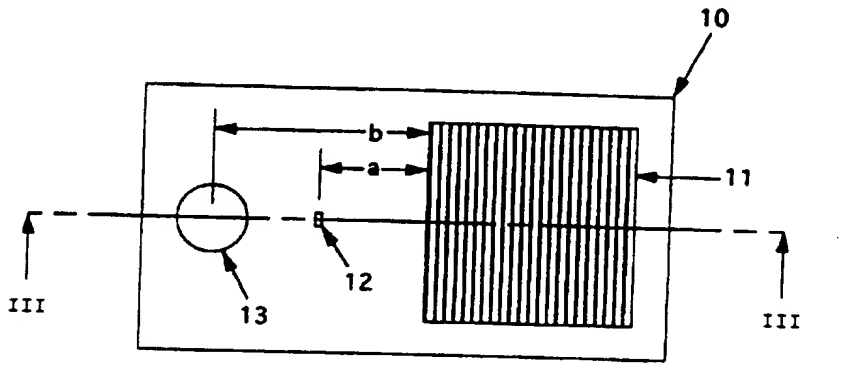


Figure 2

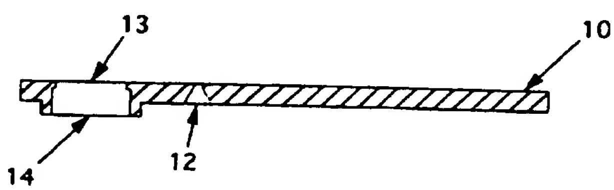


Figure 3

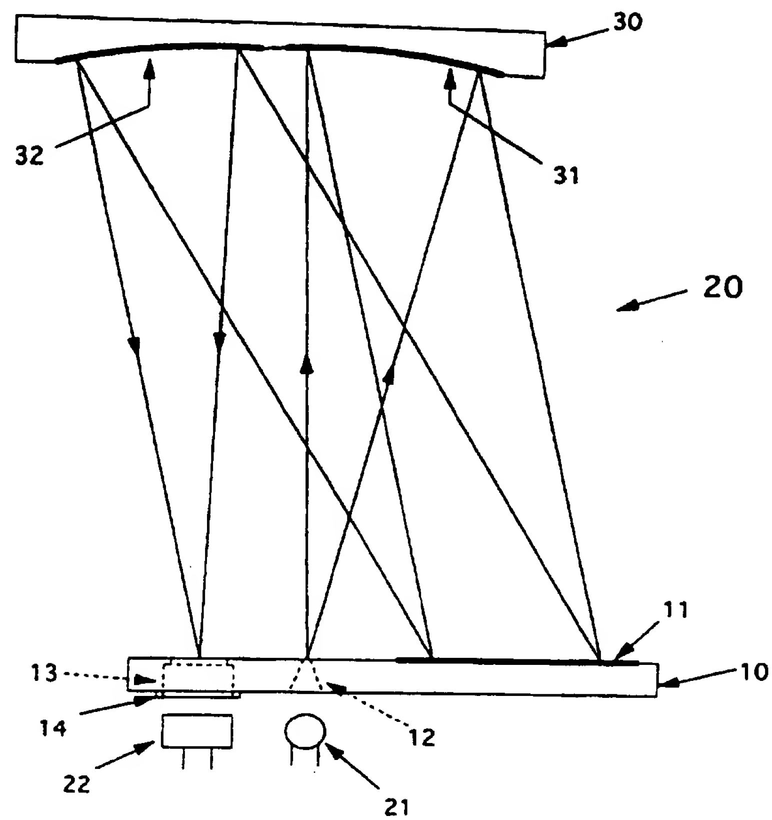


Figure 4a

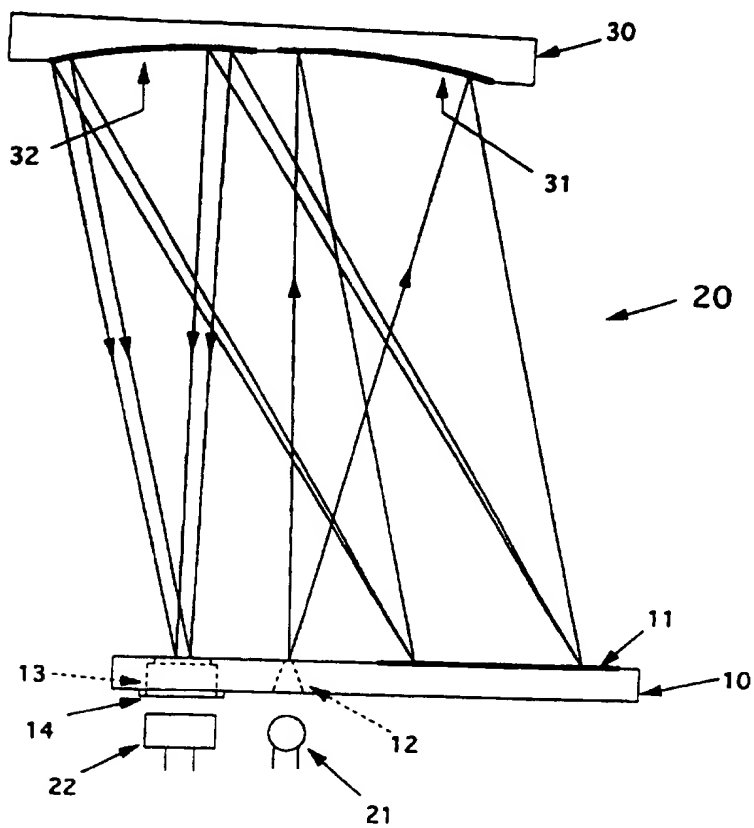


Figure 4b

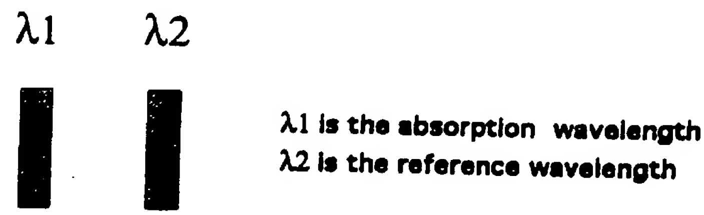


Figure 5a

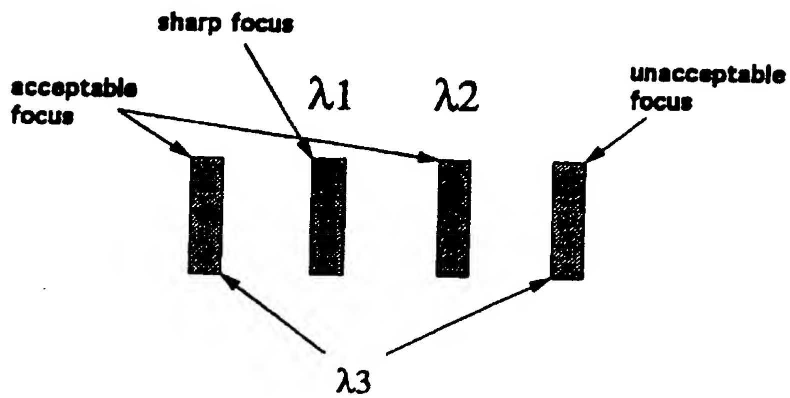


Figure 5b

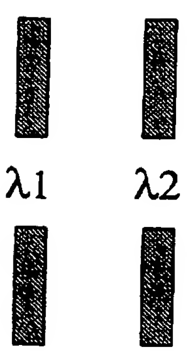


Figure 5c

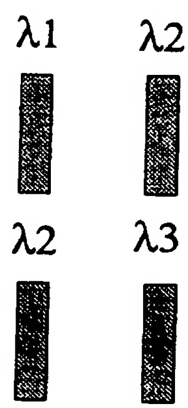


Figure 5d

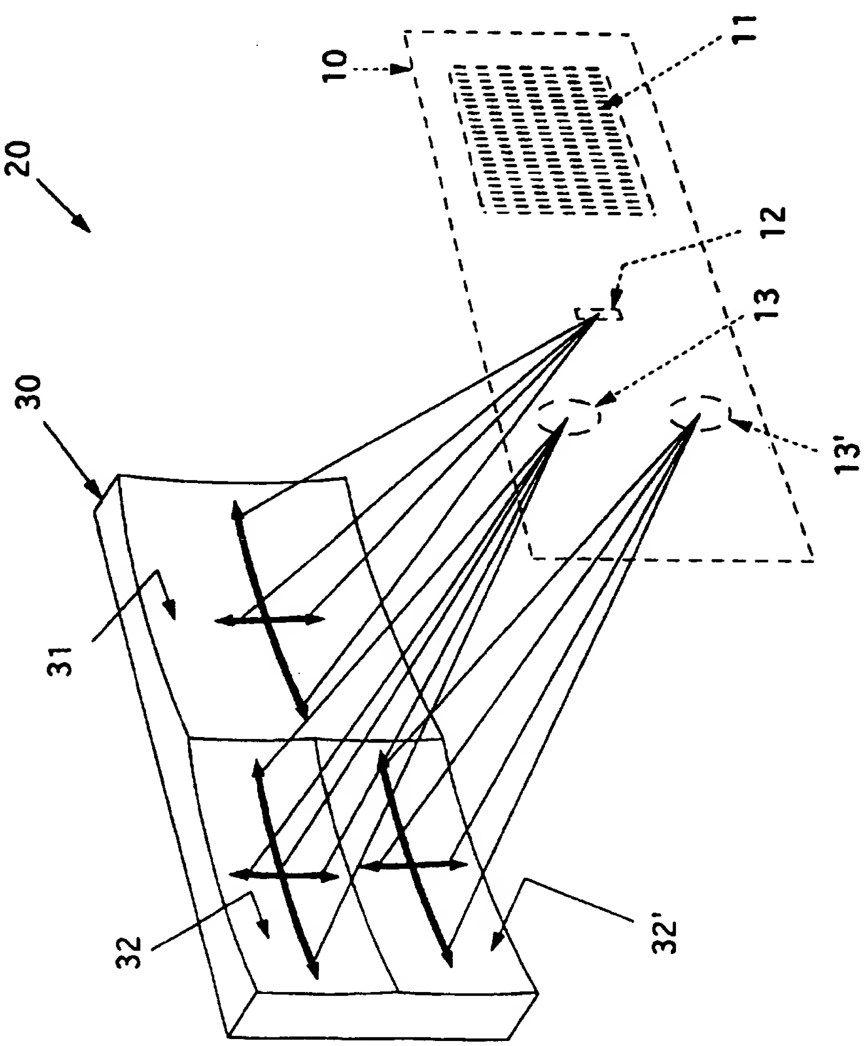


Figure 6

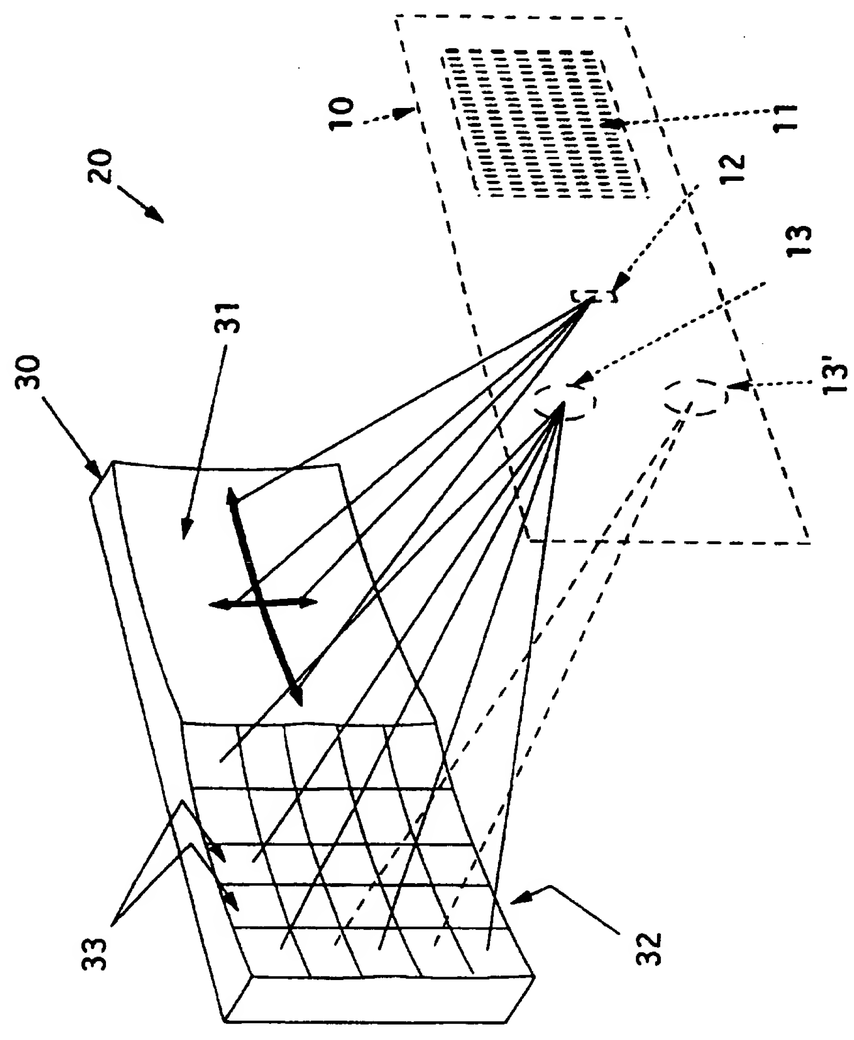


Figure 7

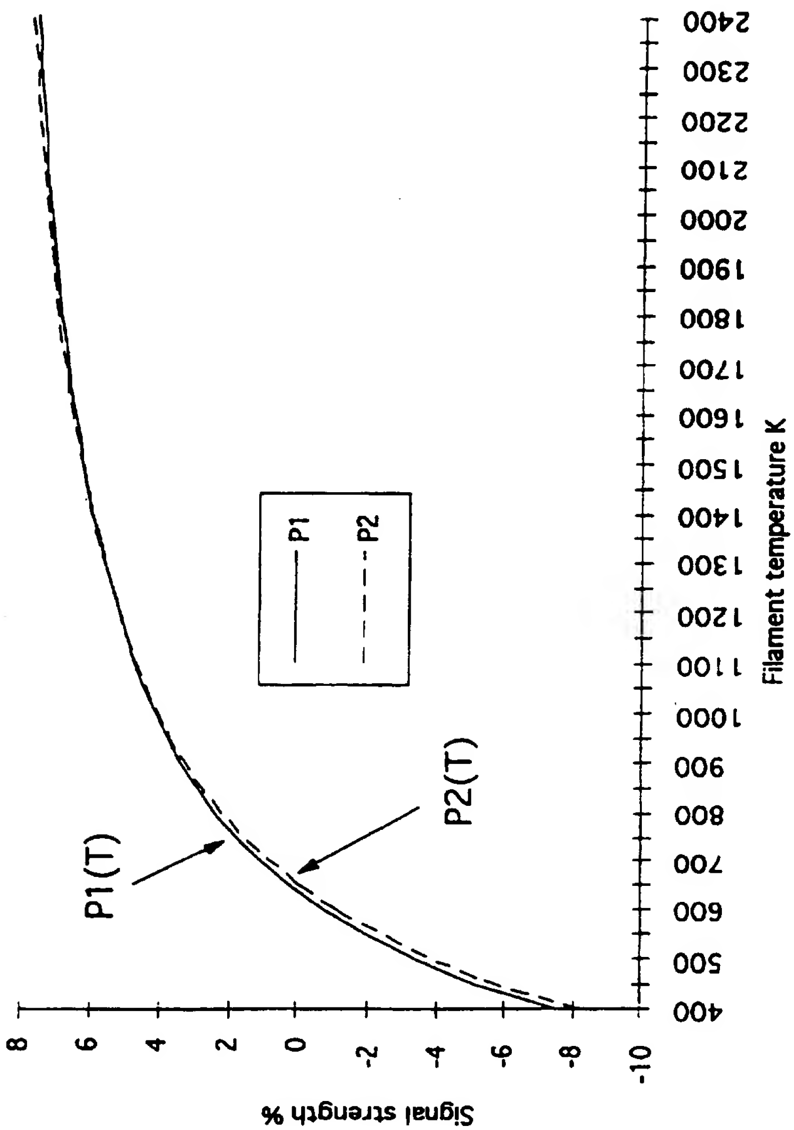

Signal strength %
8
6
4
2
0
-2
-4
-6
-8
-10
Filament temperature K
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
P1
P2
P1(T)
P2(T)

Figure 8

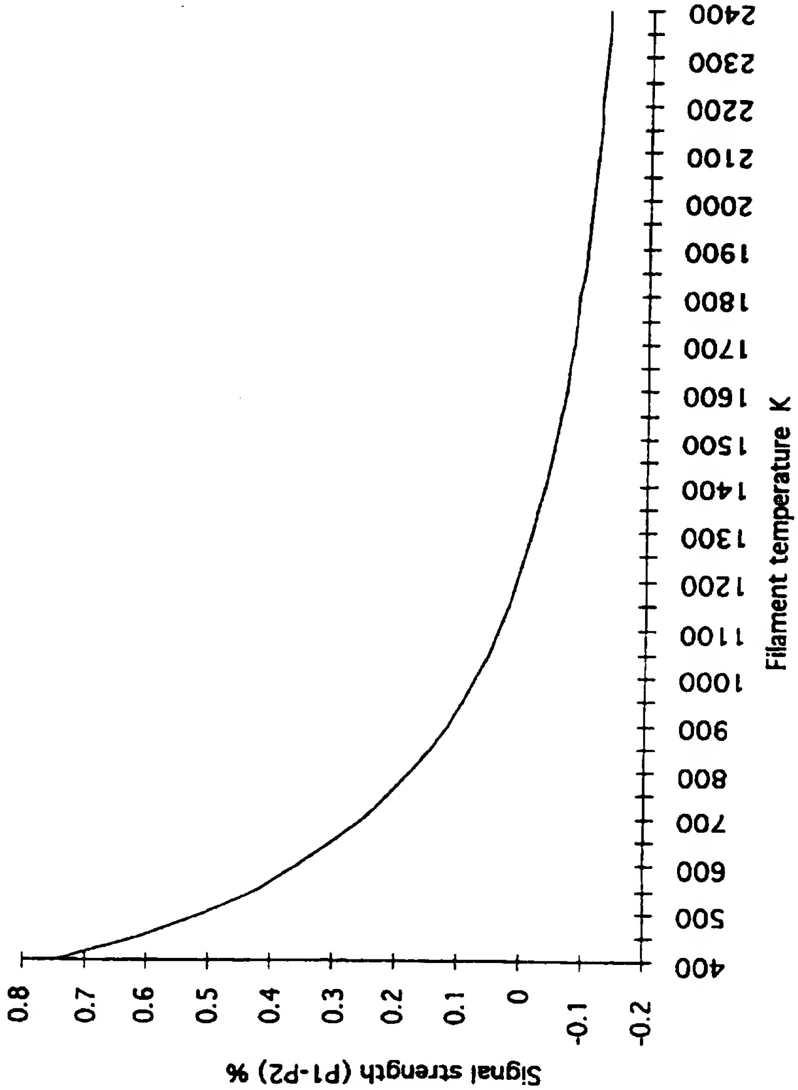
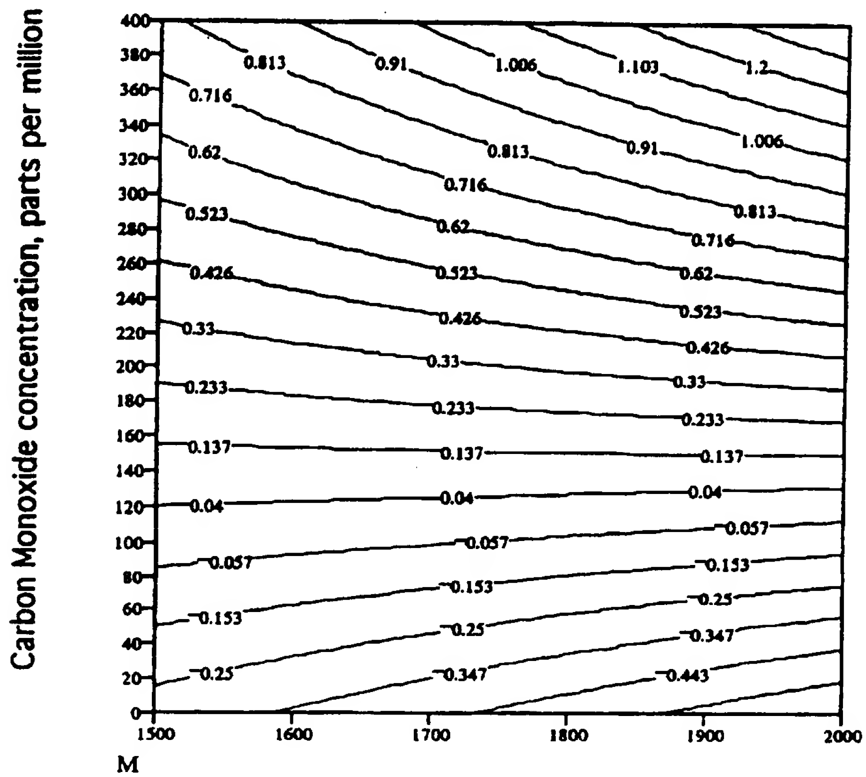

Signal strength (P1-P2) %
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
Filament temperature K

Figure 9



Filament temperature, K

Figure 10

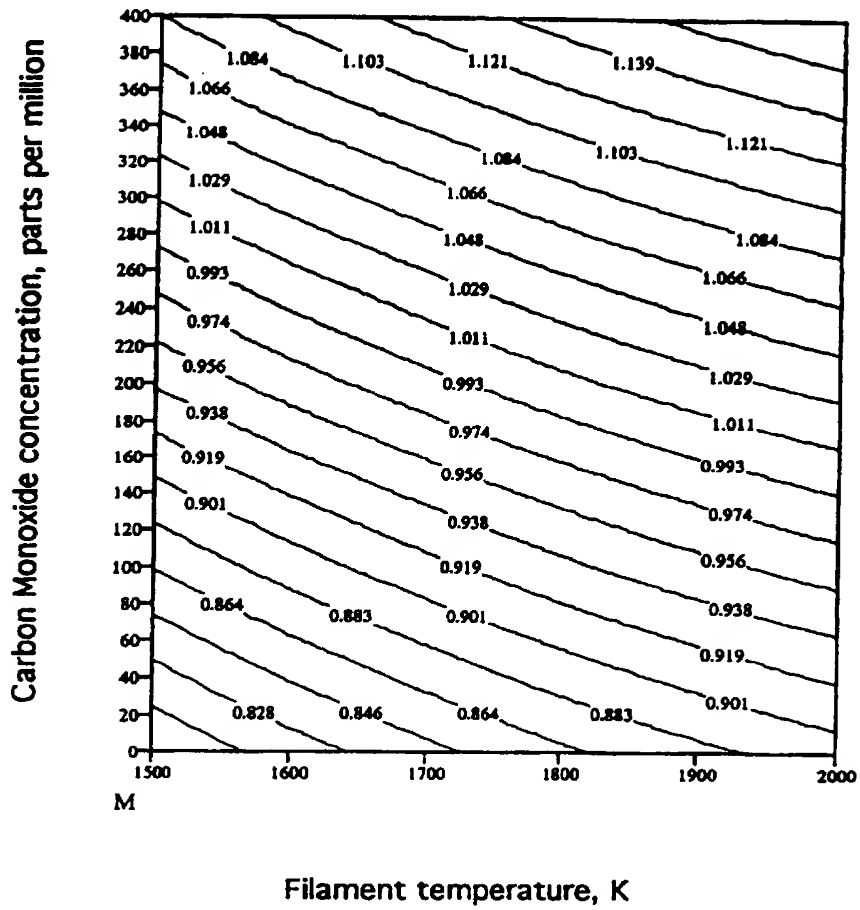

Carbon Monoxide concentration, parts per million
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
1500
1600
1700
1800
1900
2000
M
1.084
1.103
1.121
1.139
1.066
1.048
1.084
1.103
1.121
1.029
1.066
1.011
1.048
1.084
0.993
1.029
1.066
0.974
1.011
1.048
0.956
0.993
1.029
0.938
0.974
1.011
0.919
0.956
0.993
0.901
0.938
0.974
0.919
0.956
0.864
0.883
0.901
0.938
0.919
0.828
0.846
0.864
0.883
0.901
Filament temperature, K

Figure 11

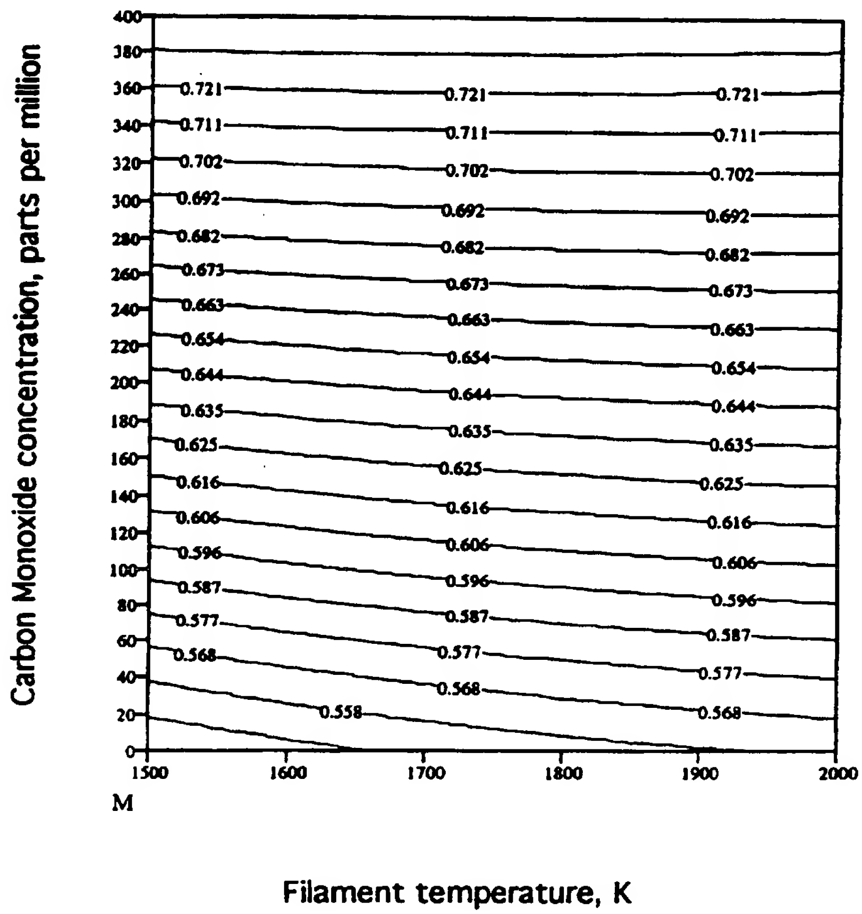

Carbon Monoxide concentration, parts per million
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
0.721
0.711
0.702
0.692
0.682
0.673
0.663
0.654
0.644
0.635
0.625
0.616
0.606
0.596
0.587
0.577
0.568
0.558
1500
1600
1700
1800
1900
2000
M
Filament temperature, K

Figure 12

INTERNATIONAL SEARCH REPORT

Intern.   al Application No
PCT/GB 97/01797

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   G01J3/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6   G01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	WO 97 02475 A (LOCKHEED MARTIN ENERGY SYSTEMS) 23 January 1997	1-4,8, 10,11, 14, 16-19, 22,23
	see page 3, line 1 - line 14 see page 4, line 8 - page 5, line 27 see page 7, line 16 - line 22; figure 3 ---	
X	PATENT ABSTRACTS OF JAPAN vol. 004, no. 184 (P-041), 18 December 1980 & JP 55 126832 A (HASUMI RITSUO), 1 October 1980,	1,5-11, 13
Y	see abstract --- -/--	3,14

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

2

Date of the actual completion of the international search	Date of mailing of the international search report
6 October 1997	22.10.97

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Navas Montero, E

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INTERNATIONAL SEARCH REPORT

Inten nal Application No
PCT/GB 97/01797

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	PATENT ABSTRACTS OF JAPAN vol. 004, no. 184 (P-041), 18 December 1980 & JP 55 126831 A (HASUMI RITSUO), 1 October 1980,	3,17
A	see abstract	1,16

Y	DE 26 00 371 A (INSTRUMENTS SA) 8 July 1976	14
A	see page 4, line 18 - page 5, line 29; claims 1,3,4; figures 2,3	1

X	PATENT ABSTRACTS OF JAPAN vol. 004, no. 031 (P-002), 18 March 1980 & JP 55 006320 A (HASUMI RITSUO), 17 January 1980,	1,16,19, 22
Y	see abstract	17

2

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INTERNATIONAL SEARCH REPORT

.formation on patent family members

Inte ›nal Application No

PCT/GB 97/01797

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9702475 A	23-01-97	AU 5436696 A	05-02-97
DE 2600371 A	08-07-76	FR 2297431 A JP 51094287 A	06-08-76 18-08-76